2. Aviation System Overview

During the next 10-15 years, the period addressed by this strategy, the aviation system will continue to be essential to the U.S. national security, economy, and quality of life for U.S. citizens, and is expected to continue its current pattern of growth. As early as 2013, U.S. enplanements are projected to reach nearly 1.1 billion passengers a year – 50 percent more than they carried in 2001. The projected increase in passengers and aviation activity will further strain a system that, prior to September 11, 2001, was already perceived as near full capacity. Over the next decade it will be critical to increase both capacity and efficiency in the NAS. In the period 2003-2013, demand for aerospace transportation services is projected to increase at average annual rates of 3.8 percent for domestic enplanements and 5.5 percent for cargo services.[4]

In addition, the aerospace enterprise will continue to evolve in important ways in seeking to satisfy and profit from this demand. In what has become a truly global marketplace, competitive forces and popular insistence on efficient government will continue a trend toward deregulation of air carriers and privatization of nationally owned airlines. Regardless of public or private ownership, the need for global reach has generated a varied and extensive set of cooperative arrangements and alliances among carriers seeking to provide convenient and seamless service anywhere in the world. A similar process is visible in the linking of major airlines with regional airlines and commuter services that can serve many localities for both direct and feeder flights.

For at least the next several years, security issues will be a central part of the aviation environment. Security initiatives will generally affect costs, aviation system processes and procedures, and overall system performance and convenience during the transition to new ways of operating. Depending on the success with which future terrorist attacks are prevented, higher costs and traveler concerns could significantly constrain near-term growth. However, it is assumed here that the global response to the tragic events of September 11 will be sufficiently successful that, in the long run, security impacts on air transportation supply and demand will be relatively modest.

The aerospace environment is increasingly dynamic. The fleet of regional jets is growing rapidly. One major manufacturer is planning a new airliner seating more than 500 passengers, and another is designing a transport to travel at nearly the speed of sound. Some industry observers see higher enplanements as driving a move back toward increased direct flights and less reliance on hub-and-spoke operations. Expanded use of smaller airports, facilitated by satellite-based navigation and landing systems and continued expansion of the regional and business jet fleet, will be widespread. Carrier strategies relating to routes, aircraft size, schedules, and other matters will be varied and volatile, driven in part by mergers and alliances, including international agreements.

Fuel cost is a large component of airline expense, and major changes in the price of petroleum

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[4] *FAA Aerospace Forecasts Fiscal Years 2002-2013,* March 2002.

can have a significant impact on seat miles offered, or ticket prices, and ultimately on passenger demand. The competitive environment for airlines is reflected in the FAA forecast of declining yield (revenue per passenger mile), which could put continuing pressure on service quality and ability to make improvements that could relieve congestion pressures.

Although currently in abeyance, the steady growth in demand in recent years has already strained airspace system capacity. There are many impediments to the FAA's ability to significantly increase capacity. Equally important are the decisions by airlines, airport operators, and Congress as to how the available capacity should be managed and used. The closer the airspace comes to maximum usable capacity, the more the system is vulnerable to any deviation from nominal conditions, such as adverse weather, with consequences and delays that can quickly spread across the entire network. Schedules planned around capacity under good conditions, and recovery flexibility, will inevitably suffer when those conditions do not prevail.

A key characteristic of this evolving industry structure is a continual search for new business strategies and relationships suited to a highly competitive free market environment. At the same time, this freedom has also had the consequence of removing constraints that previously played an important role in allocating system capacity—gates, landing slots, airspace, etc.—so that it is proving a difficult challenge to find means of avoiding or mitigating congestion and the resulting delays. Under these circumstances there is widespread concern that modernization of the NAS, development of improved procedures, and revised air carrier operational strategies will not be sufficient to relieve current problems, and will not be able to respond to the steadily growing level of traffic. Similar issues can be expected on a global scale.

Safety

Outlook

As the aviation system grows, so, too, do concerns for safety, which will remain a critical and highly visible government responsibility. The growth of transportation activity, even with level or declining accident rates, could yield a significant and highly visible increase in the absolute number of incidents, deaths, and injuries. To a large degree, countermeasures have been developed for the historically dominant accident causes, leaving the more difficult challenges, as well as new emerging problems, still to be addressed.

Over the past several decades, dramatic progress has been made in aviation safety (see Figure 2-1). While encouraging, the actual outcome of trends cannot be predicted with certainty. The data indicate a possibility that the rate of improvement could be slowing compared to that experienced in earlier years, emphasizing the magnitude of the challenge implied by the FAA goal of an 80 percent reduction by 2007 from the 1996 level. A similar pattern is seen for general aviation (GA) (see Figure 2-2).

Technological advances, particularly in communication, information, and automation systems, offer the potential to contribute significantly to a continued decline in the accident rate for both commercial and GA. Systems already deployed, or now being developed will enhance

situational awareness (ground proximity, runway incursions and airborne collision situations) for
GA pilots, commercial flight crews, and controllers.

Future development of technological aids—e.g., better weather information, advanced avionics, on-board flight management systems, aircraft "health" monitoring systems, and other automation aids, all reflecting principles of human-centered design— can prevent many other types of accidents, as will the growing understanding of aircraft component and system failure modes.
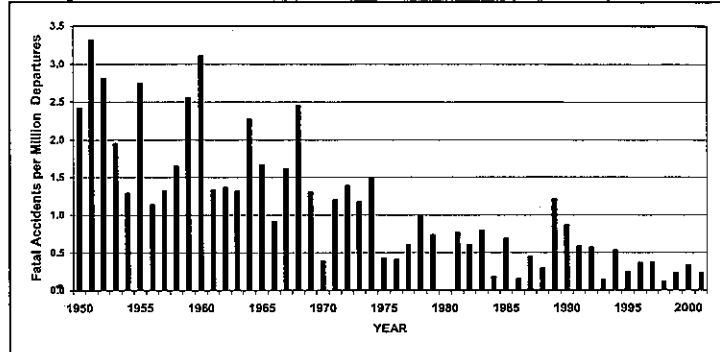

Figure 2-1. Fatal accidents per million departures for U.S. Part 121 scheduled service airlines, 1950-2001. Accidents due to sabotage are not included. (Source: Air Transport Association.)

A growing role will be played by sophisticated data collection and analysis systems that make accident precursors much more visible. This will enable more effective and timely introduction of technological, operational, maintenance, and inspection-related remedies.

However, it will be of the utmost importance to remain alert to the possibility of new failure modes and "learning-curve" problems associated with these changes. Timely validation,
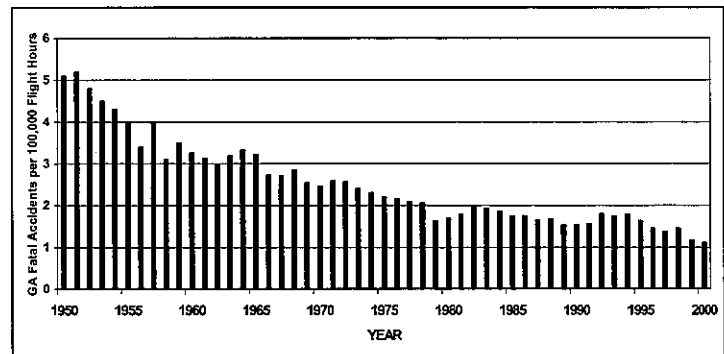

Figure 2-2. Fatal accidents per 100,000 flight hours for general aviation, 1950-2000. (Source: Aircraft Owners and Pilots Association, based on FAA and National Transportation Safety Board data.)

certification, and industry-wide equipage of highly sophisticated software-based safety-critical systems pose a daunting challenge, and similar concerns accompany use of any other new or advanced equipment, materials, designs, and procedures which may be associated with airspace system modernization and the introduction of new aircraft and subsystems. The response to these challenges will require R&D to develop full understanding of the system components, testing and inspection tools, software validation processes, human factors considerations, and focused failure mode analyses.

Globalization and changes in industry structure and practices could also compromise safety. The partitioning among many external parties of maintenance and other functions traditionally performed by a single airline, or global alliances among many carriers, could blur responsibilities and diminish oversight capabilities. A similar issue arises with respect to an increased level of overseas design and manufacture. Vigorous competition, if unconstrained, and associated pressures for lowering costs, might have adverse safety consequences if monitoring and oversight are not sufficient. Overall, harmonization of standards, practices, and procedures will require substantial effort.

As in other industries, aviation could be hard-pressed to find a workforce fully qualified to deal with new technologies, particularly in the automation and computer areas. Still another complicating factor is the likelihood of a significantly broader mix of air traffic—from enhanced general aviation aircraft and a rapidly growing fleet of business and regional jets to tiltrotors, unmanned air vehicles, dirigibles, and space vehicles.

Current and Future Issues, Challenges, and Opportunities

Topics of significance to aviation safety and associated R&D in the next decade include:

- The potential for terminal area and airport surface collisions.

- The introduction and certification of new technologies, with special emphasis on software reliability and failure modes in critical highly automated applications.

- New concerns associated with aging aircraft, e.g., mechanical and electrical systems, and "aging software," particularly in embedded systems.

- Human factors issues regarding the integration of increased flight deck and ground automation.

- New human-centered designs in cockpit/flight deck and air traffic control and management systems.

- The roles and responsibilities of flight crews and controllers in high-technology automation-rich environments.

- The need to collect and analyze safety-relevant operational data.

- The introduction of new technologies with possible new failure modes.

- The unintended adverse safety consequences associated with security countermeasures.

- An increase in the numbers of commercial space launches and landings, and associated sites, and increased complexity of space launch vehicles.

- The need to protect, detect, respond and recover from malicious cyber attacks.

System Efficiency

Outlook

Modernization of the NAS and its global counterpart, with the continued evolution of sophisticated technology and the introduction of new operational concepts, holds the potential to permit significant safe reduction of aircraft separation standards in some circumstances, reduce the consequences of adverse weather conditions, and permit more flexible and efficient use of en route airspace. In the future, automation tools will support greater optimization in system-wide traffic management. Collaboration among controllers, airline flight dispatchers, and flight crews in key decisions will enable more effective use of the airspace.

The potential for dispersal of some air travel to less crowded and smaller airports by direct-flight regional jets, small transports, and business aircraft will be enhanced by use of GPS-based navigation and positioning systems and other avionics equipment. Advances in technology could lead to significantly expanded GA activity, making greater use of controlled airspace. Additionally, the move from turbo-prop to jet aircraft by regional carriers will continue to increase demand for entry into the high-level en route sectors.

The lengthier, high-traffic routes will continue to be served predominantly by relatively large aircraft, with some, primarily on intercontinental routes, potentially carrying more than 500 passengers. Shorter routes, in particular, are likely to see increased use of smaller aircraft, which offer the market advantage of greater frequency of flights. The ability of hub-and-spoke route structures to provide attractive schedules for a large number of smaller cities would assure a continuation of this basic strategy, though the number of routes on which direct flights are offered is likely to increase with enplanements and further penetration of regional jet aircraft. The high rate of growth of international aviation could contribute to a similar trend toward direct flights to and from many inland cities, rather than the current high concentration in a few gateway airports.

This growth will occur in the context of an airport and air traffic management system that is already perceived as substantially overloaded, contributing to frequent and sometimes widespread congestion and delays in response to adverse weather and other circumstances. To meet the currently projected demand in 2010 and beyond, it will be necessary not only to respond to today's problems, but also to nearly double the traffic handled. A substantial shortfall in the capacity of the aviation system, and in its performance characteristics, would have serious implications for personal mobility and the economic health of the nation, and would be especially detrimental in particular localities. Given the time required to develop, test, and implement innovative solutions, the foundation of meeting the post-2010 challenges must be initiated within the next few years.

The problem is not confined to en route and terminal airspace traffic management. Congestion on taxiways and at gates is an additional source of delays and inefficiencies. Other relevant constraints include environmental limits associated with noise and other emissions, uncertainty concerning localized near-term weather conditions, and avoidance of wake vortices. Runway capacity is a critical limitation, with expansion virtually precluded at many airports as a result of environmental concerns and lack of available land. From the perspective of air travelers focusing on door-to-door travel time, the availability and capacity of ground transportation access and services at airports, and of the terminals themselves, will also affect the convenience, ease, and speed of air travel.

Solutions to this challenge must be consistent with the absolute requirement that safety not be compromised by any changes in operational strategies and procedures, equipment, software, and other system elements. Implementation of innovative technology and operational strategies will require a lengthy period for user training and for installation of sophisticated avionics not only in the commercial aviation sector, domestic and international, but also for more than 200,000 general aviation aircraft and over 300,000 pilots. A high degree of global compatibility and

interoperability will be required, implying a need to obtain international consensus and collaboration.

Overall, the goal of providing a level of system capacity and performance meeting the needs of users through 2010 will require a major effort and large investments. To make the necessary continuing improvements for traffic anticipated in the decade beyond 2010 is truly a daunting undertaking. To increase capacity and better match available capacity to demand for air travel, fundamental changes will be required in operating procedures, technology, airspace design, and airport infrastructure. Dramatic advances will be required in airport arrival/departure rates, airspace congestion, and reduction of the effects of weather conditions, both en route and at airports. Long-term success in this endeavor will require that the FAA Operational Evolution Plan[5] (OEP) be supported with the fullest identification and exploitation of relevant technologies and associated operational concepts.

Current and Future Issues, Challenges, and Opportunities

System Efficiency topics with a potential bearing on R&D in the next decade include the need to:

- Reduce system delays.

- Improve system performance in bad weather, especially low ceilings and visibility.

- Increase the flexibility and adaptability of system architecture to allow for data sharing to support collaborative decision making and common situational awareness.

- Increase system capacity to meet domestic and global demand.

- Improve the rate of technical and procedural evolution of the air traffic management system:
Implementation.
Human performance and limitations.
- Improve pavement design and construction standards.

- Provide air traffic services for a wider range of aircraft—dirigibles, unmanned air vehicles, next-generation general aviation aircraft, high-performance business jets, jumbo airliners, space vehicles, and payloads.

- Update and apply satellite-based navigation and positioning system technology, and ensure the FAA's role in shaping and exploiting that evolution.

- Increase power and affordability of information technologies, particularly with respect to automation applications.

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[5] *Operational Evolution Plan Version 4.0*, FAA, Dec. 2001.

Environmental Compatibility

Outlook

Environmental compatibility is an area in which public sensitivity is already high and may well increase further. Five years ago the National Science and Technology Council predicted "environmental issues are likely to impose the fundamental limitation on air transportation growth in the 21st century."[6] The apparent accuracy of this assessment has not changed in the intervening years.

The noise associated with aircraft operations will continue to be a contentious issue into the future, delaying or precluding construction of new runways in some cases, in spite of the phase-in of significantly less noisy aircraft. Similar objections will continue to arise in response to attempts to institute or expand air carrier service in the smaller airports that are currently underused.

Compliance with air quality standards is a major focus for many airports, and will be a growing challenge in coming years as air traffic, and associated landside emission sources grow. Responses to this concern will affect aircraft operations as well as the movement of service vehicles, airport access, and other activities. Other constraints include land use and local road traffic issues, which often preclude expansion of facilities, or at least make it a difficult, expensive, and lengthy process. Cumulatively, environmental issues can be expected to pose a significant constraint on airport expansion throughout the next decade.

Given the increasingly global scope of air transportation, handling challenging environmental issues will be made even more complex and difficult by the need to develop solutions that can achieve international agreement and deployment. The starting point for meeting these challenges is a solid foundation of scientific data and analysis, coupled with a comprehensive understanding of airport operations.

Current and Emerging Future Issues, Challenges, and Opportunities

Topics of significance to environmental compatibility, and to associated R&D, in the next decade include the need to:

- Create an environmentally friendly global air transportation system.
- Harmonize U.S. and international standards.
- Conduct comprehensive environmental assessments, including both airside and landside through models and data.
- Analyze and simulate alternative mitigation strategies, including economic factors and stakeholder impacts.

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[6] *Goals for a National Partnership in Aeronautics Research and Technology,* NSTC, 1995.

- The impacts caused by the large growing variances between expected computational power and the capability to effectively transport exponentially increasing amounts of data and information.

Technology Considerations

New aviation technologies are being introduced into the NAS at a rapid rate. Perhaps the most visible area of advance is information and digital electronics technology. Computational power and memory capacity has for decades been doubling every 18 months, yielding a ten-fold increase over a 5-year period. If this rate of improvement continues, as is widely expected, the result would be a 1,000-fold increase by 2015. It is difficult to predict specific consequences of an advance of this magnitude, but dramatic changes are very likely in power and affordability of specific technologies and in the functionalities they enable. Communications technology, based in large part on digital electronics, will be similarly affected, as will applications of displays, sensors and actuators, and other components.

In the next decade these technologies will enable virtually any individual to have convenient, low-cost, and accurate knowledge of his or her position and environment, to communicate that and other information to any other entity, and to access, either locally or at a distance, enormous data resources. Satellite-based navigation positioning will be particularly critical for aerospace applications. Voice recognition and synthesis will be a common form of human-system interface. Enhanced vision technology, automated data link, and advanced surveillance information (e.g., non-radar-based solutions) will move rapidly from the laboratory to operations.

The availability of greater communications, sensing, and computer power will enable pattern recognition and functional automation far beyond anything previously possible. A variety of technologies offer the potential of a much tighter coupling—both input and output—between humans and the systems they operate or monitor. These technological changes will enable a broad range of new concepts, functions, and designs. Some will ultimately transform specific systems, activities, and even behavioral patterns.

When large-scale changes to capabilities or affordability of technology occur the results are not simply better performance, but also lower cost for systems. However, implementation of such advances is often disruptive of existing practices. (This effect has been highly visible in the information technology arena.) They yield conceptually new products and applications, created by the existence of new functionalities, innovative ways of operating, evolving institutional realignments, and changed markets. It is seldom possible to predict in advance the nature and magnitude of the long-term impacts of emerging technologies. Many fail, and those that are successful often evolve in ways and serve markets not anticipated even by their champions.[7] Other unintended consequences can be the introduction of new risks and failure modes derived from the complex interaction of innovations in systems and processes. This pattern, which is

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[7] This concept is developed in Clayton Christensen's 1997 book, *The Innovator's Dilemma*, published by the Harvard Business School Press.

becoming increasingly characteristic of the times, will undoubtedly be an important factor in the course of transportation and aerospace in coming decades.

Innovations, disruptive or not, will contribute to the development of vehicles with improved operational characteristics, operating in a framework of dramatically enhanced traffic management technology. Many challenging issues and complications, including the following, however, will accompany the improvements:

- Safe and effective integration of humans and automated systems.
- Attainment of a solid understanding of the properties and failure modes of new materials and components prior to application.
- Full characterization and understanding of the operation and failure modes software-based large-scale distributed systems.
- System designs that are suited to the continued incorporation of improved technology, and facilitate evolution to alternative operational concepts.